PATENT SPECIFICATION

633,943

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PROVISIONAL SPECIFICATION

Improvements in or relating to Compound Sheet Dielectric Structures

I, JOHN BETTELEY BIRKS, of Ministry of Supply, London, a British subject, do hereby declare the nature of this invention to be as follows.

This invention relates to compound sheet dielectric structures such as those used in the construction of protective housings for electro-magnetic aerial systems, spacing, supporting or sealing members for electromagnetic waveguides, transmission lines and other applications of like nature, more particularly with relation to ultra-high frequency e.m. oscillations.

Although not limited thereto, the invention will be described with reference to electromagnetic aerial systems. In mounting such aerial systems which may be large and/or movable, e.g. rotatable, on land, ships, projecting from or inside aircraft or elsewhere, it is often necessary to protect them from wind and the elements by housing the aerial system in a cylindrical or other suitably shaped housing of dielectric material. Such a housing introduces two sources of loss of electromagnetic power, absorption loss in the propagation of the radiation through the housing, and reflection loss due to reflection of part of the radiation incident on the housing. The absorption loss may be minimised by the use of low-loss dielectric materials, but to reduce the reflection loss it has been necessary to choose suitable thicknesses for the dielectric materials from which the housings are constructed, such thicknesses being determined from the wavelength at which the aerial system operates, and from the dielectric properties of the materials used.

It is common practice for such housings to be constructed from a single, uniform dielectric material, such as that known under the registered Trade Mark "Perspex." In this case the power reflection coefficient (percentage of incident power reflected) for a plane electromagnetic wave normally incident on a plane dielectric sheet is given by

$$R^2 = \frac{4r^2 \sin^2 A}{(1-r^2)^2 + 4r^2 \sin^2 A} \qquad (1)$$

where

$$r^2 = \frac{(\sqrt{K}-1)^2}{(\sqrt{K}+1)^2} \qquad (1.1)$$

$$A = \frac{2\pi t \sqrt{K}}{\lambda} \qquad (1.2)$$

k = dielectric constant of material.
t = thickness of material.
λ = wavelength.

With such single sheet construction, three methods may be used for keeping the reflection coefficient small.

(a) The use of a material of thickness small compared with the wavelength. This method is restricted in practice by the mechanical requirements which have to be met by the housing, which set a minimum permissible value on t.

(b) The use of a material of thickness equal to a multiple of a half-wavelength in the dielectric (i.e. $t = \dfrac{n\lambda}{2\sqrt{k}}$, where n is any positive integer). This method often results in housings that are too bulky or too heavy, or alternatively the tolerances on the thickness which it is necessary to impose to keep R^2 small may be too stringent to be met in practice.

[*Price* 2/-]

Price 3s. 6d.

(c) The use of a material of low dielectric constant, K, in any thickness. Although solid materials with sufficiently low K (order of 1.6 or less) are available, their mechanical properties are not in general adequate for them to be used unreinforced.

This invention is concerned with the design and construction of a compound sheet dielectric structure or material which is particularly suitable for dielectric housings, and which offers definite advantages in many cases over those described above. The structure according to the invention consists of two similar thin dielectric sheets, separated by a particular thickness of dielectric material or structure, of low effective dielectric constant. This construction is hereinafter referred to as a " sandwich " construction, the two similar thin dielectric sheets being known as the " skins," and the separating material or structure as the " core." The dimensions of the sandwich, and in particular the thickness of the core, are chosen in such a manner that the reflections of incident electromagnetic radiation from the two skins cancel or partially cancel, so that the power reflection coefficient of the complete sandwich construction is small.

When suitable materials of high strength and/or stiffness are used for the skins, and low density materials or structures are used for the core, the complete sandwich is an efficient mechanical construction, combining light weight with high strength and stiffness. Woven fibreglass cloth, thin Perspex sheet and synthetic resin fibre-glass laminate are among the materials found suitable for use as skin materials. Suitable core materials include expanded Perspex, expanded ebonite and other expanded, foamed or cellular materials, and tubular, grid, lattice and other core spacing structures, made from paper, plastics and other materials.

The electrical design data applicable to sandwich constructions are given below. The optimum value L_0 of the core thickness to give zero reflection of power for an electromagnetic wave incident normally on the construction is given by

$$L_0 = \frac{\lambda}{2\pi\sqrt{s}} \tan^{-1} \frac{2\sqrt{sk}\,(k-1)\tan D}{(k^2-s)\tan^2 D - k(s-1)} \quad (2)$$

$$\text{where } D = \frac{2\pi\sqrt{k}\,d}{\lambda} \quad (2.1)$$

s, k = dielectric constants of core and skins respectively.
d = thickness of each skin.
λ = wavelength.

In practical applications, due to the shape of the dielectric housing, the incident radiation is not always at normal incidence to the sandwich structure. In this case the optimum value of core thickness to give minimum reflection depends on the angle of incidence, I, and on the direction of polarisation of the incident wave. For perpendicular polarisation (electric vector perpendicular to the plane of incidence), oblique incidence, the optimum value of core thickness is given by

$$L_{01} = \frac{\lambda}{2\pi\sqrt{s_1}\cos I} \tan^{-1} \frac{2\sqrt{S_1 k_1}\,(k_1-1)\tan D_1}{(k_1^2-S_1)\tan^2 D_1 - k_1(S_1-1)} \quad (3)$$

$$\text{where } D_1 = \frac{2\pi\sqrt{k_1}\,d\cos I}{\lambda} \quad (3.1)$$

$$K_1 = \frac{k-\sin^2 I}{\cos^2 I} \quad (3.2)$$

$$S_1 = \frac{s-\sin^2 I}{\cos^2 I} \quad (3.3)$$

s, k, d, I are defined as above.

For parallel polarisation (electric vector parallel to the plane of incidence) the optimum value of core thickness is given by

$$L_{02} = \frac{\lambda}{2\pi\sqrt{S_1}\cos I} \tan^{-1} \frac{2\sqrt{S_2 k_2}\,(k_2-1)\tan D_1}{(k_2^2-S_2)\tan^2 D_1 - k_2(S_2-1)} \quad (4)$$

$$\text{where } S_2 = \frac{S_1^2}{s} \quad (4.1)$$

$$K_2 = \frac{k_1^2}{k} \quad (4.2)$$

D_1, s_1, k_1, are given by (3.1) (3.3) and (3.2) respectively

s, k, d, I are defined as above.

Formulæ (2) (3) and (4) give the optimum values of core thickness, for the three incidence cases considered.

For practical purposes, however, it is often desirable to use a sandwich construction of uniform core thickness for the complete aerial housing, although the angles of incidence subtended by the radiation at different parts of the housing may vary. In this case the sandwich may be designed to give minimum reflection over the complete range of incidence angles involved, by using the optimum value of core spacing for some incidence angle intermediate between the two extreme angles of incidence in the range. This optimum core spacing will be that value which gives equal, small reflection coefficients at the two extreme incidence angles.

In order to arrive at a design suitable for a range of incidence angles it may be necessary to evaluate the actual values of the reflection coefficient of a sandwich at various angles of incidence, the formulæ for which are given below.

The reflection coefficient of a sandwich is given by

$$R^2 = \frac{4r^2 \sin^2 A}{(1-r^2)^2 + 4r^2 \sin^2 A} \qquad (1)$$

$$r^2 = \frac{r_1^2 + r_2^2 + 2r_1 r_2 \cos B}{1 + r_1^2 r_2^2 + 2r_1 r_2 \cos B} \qquad (5)$$

and A, r_1, r_2, B have the values given below, in the 3 incidence cases.

	NORMAL INCIDENCE	PERPENDICULAR POLARISATION	PARALLEL POLARISATION
r_1	$\frac{\sqrt{k}-1}{\sqrt{k}+1}$	$\frac{\sqrt{k_1}-1}{\sqrt{k_1}+1}$	$\frac{\sqrt{k_2}-1}{\sqrt{k_2}+1}$
r_2	$\frac{\sqrt{s}-\sqrt{k}}{\sqrt{s}+\sqrt{k}}$	$\frac{\sqrt{s_1}-\sqrt{k_1}}{\sqrt{s_1}+\sqrt{k_1}}$	$\frac{\sqrt{s_2}-\sqrt{k_2}}{\sqrt{s_2}+\sqrt{k_2}}$
B	D	D_1	D_1
A	$\frac{2\pi\sqrt{s}(L-L_0)}{\lambda}$	$\frac{2\pi\sqrt{s_1}(L-L_{01})\cos I}{\lambda}$	$\frac{2\pi\sqrt{s_1}(L-L_{02})\cos I}{\lambda}$

Where L = core thickness

L_0, L_{01}, L_{02} = optimum core thicknesses given by (2), (3) and (4)

s, k, λ, I, are defined as above

s_1, k_1, s_2 k_2 are given by (3.3) (3.2) (4.1) and (4.2)

D, D_1 are given by (2.1) and (3.1).

The reflection coefficient for oblique incidence, arbitrary polarisation, may be evaluated by resolving into perpendicular and parallel polarisation components.

With the aid of the equations listed, which give a complete description of the electromagnetic reflection properties of the sandwich construction, suitable sandwich structures may be designed for any particular dielectric housing.

This invention, although particularly suitable for dielectric aerial housings, may also be applied to other structures used in conjunction with electromagnetic waves. Sandwich type dielectric spacers may be used in concentric or twin high frequency transmission lines, the design data being those given above for normal incidence. They may also be used as seals, or spacers, in hollow pipe transmission lines, or waveguides, the angle of incidence that the electromagnetic wave in the pipe subtends at the sandwich structure being determined by the dimensions of the pipe and the wavelength. For transverse electric or H waves, the polarisation is perpendicular to the plane of incidence; for transverse magnetic or E waves, it is parallel. In certain instances it may be found practicable to omit the core material, in which case the same design data may be used, if the dielectric constant, s, of the core is set equal to unity.

Dated this 11th day of August, 1945.

C. STRATTON CROSS,
Chartered Patent Agent,
Agent for the Applicant.

COMPLETE SPECIFICATION

Improvements in or relating to Compound Sheet Dielectric Structures

I, JOHN BETTELEY BIRKS, of Ministry of Supply, London, a British subject, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to compound

sheet dielectric structures such as those used in the construction of protective housings or so-called "radomes" for electromagnetic aerial systems, spacing, supporting or sealing members for electromagnetic waveguides, transmission lines and other applications of like nature, more particularly with relation to ultra-high frequency electromagnetic oscillations e.g. oscillations at frequencies of the order of 1000 Mc/sec. or higher.

Although not limited thereto, the invention will be described with reference to electromagnetic aerial systems. In mounting such aerial systems which may be large and/or movable e.g., rotatable, on land, ships, projecting from or inside aircraft or elsewhere, it is often necessary to protect them from wind and the elements by housing the aerial system in a cylindrical or other suitably shaped housing of dielectric material. Such a housing introduces two sources of loss of electromagnetic power, absorption loss in the propagation of the radiation through the housing, and reflection loss due to reflection of part of the radiation incident on the housing. The absorption loss may be minimised by the use of low-loss dielectric materials, but to reduce the reflection loss it has been necessary to choose suitable thicknesses for the dielectric materials from which the housings are constructed, such thicknesses being determined from the wavelength at which the aerial system operates and from the dielectric properties of the materials used.

It is common practice for such housings to be constructed from a single, uniform dielectric material, such as polymerised methyl-methacrylate, e.g. that known under the registered Trade Mark "Perspex." In this case the power reflection coefficient (percentage of incident power reflected) for a plane electro-magnetic wave normally incident on a plane di-electric sheet is given by

$$R^2 = \frac{4r^2 \sin^2 A}{(1-r^2)^2 + 4r^2 \sin^2 A}$$

where $$r^2 = \frac{(\sqrt{K}-1)^2}{(\sqrt{K}+1)^2}$$

$$A = \frac{2\pi t\sqrt{K}}{\lambda}$$

K = di-electric constant of material
t = thickness of material
λ = wavelength

With such single sheet construction, three methods may be used for keeping the reflection co-efficient small.

(a) The use of a material of thickness small compared with the wavelength. This method is restricted in practice by the mechanical requirements which have to be met by the housing, which set a minimum permissible value on t.

(b) The use of a material of thickness equal to a multiple of a half-wavelength in the di-electric (i.e. $t = \frac{n\lambda}{2\sqrt{K}}$ where n is any positive integer). This method often results in housings that are too bulky or too heavy, or alternatively the tolerances on the thicknesses which it is necessary to impose to keep R^2 small may be too stringent to be met in practice.

(c) The use of a material of low di-electric constant, K in any thickness. Although solid materials with sufficiently low K (order of 1.6 or less) are available, their mechanical properties are not in general adequate for them to be used unreinforced.

This invention is concerned with the design and construction of a compound sheet di-electric structure or material, which is particularly suitable for di-electric housings, and which offers definite advantages in many cases over those described above.

According to the invention there is provided a compound sheet di-electric structure of the kind described, comprising a sandwich construction of two spaced thin sheets or skins of a di-electric material separated by a medium of lower effective di-electric constant than said sheets or skins, wherein the thicknesses of the thin sheets and said medium are so chosen that the reflections of incident electromagnetic radiation from the two skins cancel, or partially cancel one another, whereby the power reflection co-efficient of the complete sandwich construction is small.

When suitable materials of high strength and/or stiffness are used for the skins, and low density materials or structures are used for the core the complete sandwich is an efficient mechanical construction, combining light weight with high strength and stiffness. Woven fibre-glass cloth, thin sheet methyl-methacrylate polymer and synthetic resin fibre-glass laminate are among the materials found suitable for use as skin materials.

Suitable core materials include expanded methyl-methacrylate polymer, expanded ebonite and other expanded, foamed or cellular materials, and tubular grid, lattice and other core spacing structures, made from paper, plastics and other materials. In some circumstances the actual construction used may be such as to leave the region between the skins substantially free of any form of material.

The accompanying drawing illustrates in Figure 1 the general form of sandwich construction of dielectric material according to the invention and in Figure 2 a typical form of radome protective housing for a rotating aerial system of an airborne radar installation to which the said dielectric material is particularly adapted for use.

As shown in Figure 1 the structure comprises two similar thin sheets or skins 10 of one dielectric material having a thickness dimension d separated by a filling or core 11, having a thickness dimension L, of a dielectric material or structure whose effective dielectric constant is lower than that of the skins 10.

The electrical design data applicable to sandwich constructions are given below. The optimum value L_o of the core thickness to give zero reflection of power for an electromagnetic wave incident normally on the construction is given by

$$L_o = \frac{\lambda}{2\pi\sqrt{s}} \tan^{-1} \frac{2\sqrt{sk}\,(k-1)\tan D}{(k^2-s)\tan^2 D - k(s-1)} \qquad (2)$$

where $$D = \frac{2\pi\sqrt{k}\,d}{\lambda} \qquad (2.1)$$

s, k = dielectric constants of core and skins respectively

d = thickness of each skin

λ = wavelength

In practical applications such as that shown in Figure 2, due to the shape of the dielectric housing, the incident radiation is not always at normal incidence to the sandwich structure. In this case the optimum value of core thickness to give minimum reflection depends on the angle of incidence, I, and on the direction of polarisation of the incident wave. For perpendicular polarisation (electric vector perpendicular to the plane of incidence), oblique incidence, the optimum value of core thickness is given by

$$L_{o1} = \frac{\lambda}{2\pi\sqrt{s_1}\cos I} \tan^{-1} \frac{2\sqrt{s_1 k_1}\,(k_1-1)\tan D_1}{(k_1^2-s_1)\tan^2 D_1 - k_1(s_1-1)} \qquad (3)$$

where $$D_1 = \frac{2\pi\sqrt{k_1}\,d\cos I}{\lambda} \qquad (3.1)$$

$$k_1 = \frac{k-\sin^2 I}{\cos^2 I} \qquad (3.2)$$

$$s_1 = \frac{s-\sin^2 I}{\cos^2 I} \qquad (3.3)$$

s, k, d, I are defined as above.

For parallel polarisation (electric vector parallel to the plane of incidence) the optimum value of core thickness is given by

$$L_{o2} = \frac{\lambda}{2\pi\sqrt{s_1}\cos I} \tan^{-1} \frac{2\sqrt{s_2 k_2}\,(k_2-1)\tan D_1}{(k_2^2-s_2)\tan^2 D_1 - k_2(s_2-1)} \qquad (4)$$

where $$s_2 = \frac{s_1^2}{s} \qquad (4.1)$$

$$k_2 = \frac{k_1^2}{k} \qquad (4.2)$$

D_1, s_1, k_1, are given by (3.1) (3.3) and (3.2) respectively.

s, k, d, I are defined as above.

Formulæ (2) (3) and (4) give the optimum values of core thickness, for the three incidence cases considered.

For practical purposes, however, it is often desirable to use a sandwich construction of uniform core thickness for the complete aerial housing, although the angles of incidence subtended by the radiation at different parts of the housing may vary. In this case the sandwich may be designed to give minimum reflection over the complete range of incidence angles involved, by using the optimum value of core spacing for some incidence angle intermediate between the two ex-

treme angles of incidence in the range. This optimum core spacing will be that value which gives equal, small reflection coefficients at the two extreme incidence angles.

In order to arrive at a design suitable for a range of incidence angles it may be necessary to evaluate the actual values of the reflection coefficient of a sandwich at various angles of incidence, the formulæ for which are given below.

The reflection coefficient of a sandwich construction is given by

$$R^2 = \frac{4r^2 \sin^2 A}{(1-r^2)^2 + 4r^2 \sin^2 A} \qquad (1)$$

where $$r^2 = \frac{r_1^2 + r_2^2 + 2r_1 r_2 \cos B}{1 + r_1^2 r_2^2 + 2r_1 r_2 \cos B} \qquad (5)$$

and A, r_1, r_2, B have the values given below, in the 3 incidence cases.

	NORMAL INCIDENCE	PERPENDICULAR POLARISATION	PARALLEL POLARISATION
r_1	$\frac{\sqrt{k}-1}{\sqrt{k}+1}$	$\frac{\sqrt{k_1}-1}{\sqrt{k_1}+1}$	$\frac{\sqrt{k_2}-1}{\sqrt{k_2}+1}$
r_2	$\frac{\sqrt{s}-\sqrt{k}}{\sqrt{s}+\sqrt{k}}$	$\frac{\sqrt{s_1}-\sqrt{k_1}}{\sqrt{s_1}+\sqrt{k_1}}$	$\frac{\sqrt{s_2}-\sqrt{k_2}}{\sqrt{s_2}+\sqrt{k_2}}$
B	D	D_1	D_1
A	$\frac{2\pi\sqrt{s}(L-L_o)}{\lambda}$	$\frac{2\pi\sqrt{s_1}(L-L_{o1})\cos I}{\lambda}$	$\frac{2\pi\sqrt{s_1}(L-L_{o2})\cos I}{\lambda}$

Where L = core thickness

L_o, L_{o1}, L_{o2} = optimum core thicknesses given by (2), (3) and (4)

s, k, λ, I, are defined as above

s_1, k_1, s_2 k_2 are given by (3.3) (3.2) (4.1) and (4.2)

D, D_1 are given by (2.1) and (3.1)

The reflection coefficient for oblique incidence, arbitrary polarisation, may be evaluated by resolving into perpendicular and parallel polarisation components.

With the aid of the equations listed, which give a complete description of the electromagnetic reflection properties of the sandwich construction, suitable sandwich structures may be designed for any particular dielectric housing or like application.

This invention, although particularly suitable for dielectric aerial housing, may also be applied to other structures used in conjunction with electromagnetic waves. Sandwich type dielectric spacers may be used in concentric or twin high frequency transmission lines, the design data being those given above for normal incidence. They may also be used as seals, or spacers, in hollow pipe transmission lines, or waveguides, the angle of incidence that the electromagnetic wave in the pipe subtends at the sandwich structure being determined by the dimensions of the pipe and the wavelength. For transverse electric or H waves, the polarisation is perpendicular to the plane of incidence; for transverse magnetic or E waves, it is parallel. In certain instances it may be found practicable to omit the core material, in which case the same design data may be used, if the dielectric constant, s, of the core is set equal to unity.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. A compound sheet dielectric structure of the kind described, comprising a sandwich construction of two spaced thin sheets or skins of a di-electric material separated by a medium of lower effective di-electric constant than said sheets or skins, wherein the thicknesses of the thin sheets and said medium are so chosen that the reflections of incident electro-magnetic radiation from the two skins cancel or partially cancel one another, whereby the power reflection coefficient of the complete sandwich construction is small.

2. A di-electric structure in accordance with claim 1, wherein the skin material chosen is one having high strength and/or stiffness and the medium separating the skins is a material or structure having a low density.

3. A di-electric structure in accordance with Claim 1 or 2, wherein the skin material employed is woven fibreglass cloth.

4. A di-electric structure in accordance with Claim 1 or 2, wherein the skin material employed is synthetic resin fibreglass laminate.

5. A di-electric structure in accordance with claim 1 or 2, wherein the skin material employed is thin sheet methyl methacrylate polymer.

6. A di-electric material in accordance with any of the preceding claims, wherein the medium separating the skins is expanded methyl methacrylate polymer.

7. A di-electric material in accordance with any of the preceding claims 1 to 5, wherein the core material employed is expanded ebonite.

8. A di-electric material in accordance with any of the preceding claims 1 to 6,

wherein the core material employed comprises a grid or lattice structure of plastic material.

9. A protective housing or radome for an electromagnetic aerial system constructed as a di-electric structure in accordance with any of the preceding claims.

Dated this 8th day of November, 1947

C. STRATTON CROSS,
Chartered Patent Agent,
Agent for the Applicant.

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Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies, price 2s. 0d. each (inland) 2s. 1d. (abroad) may be obtained.

[This Drawing is a reproduction of the Original on a reduced scale.]

Fig. 1

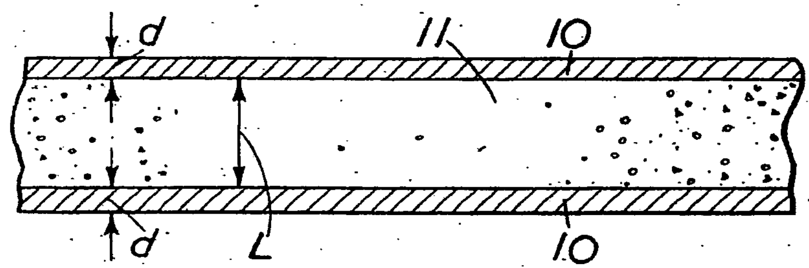
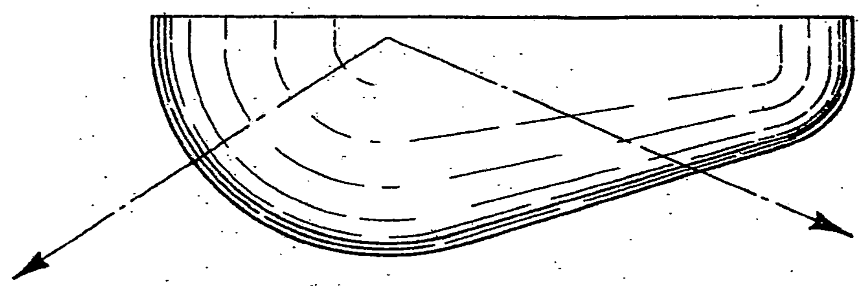


Fig. 2



H.M.S.O. (Ty.P.)